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-- **RAPPORT FINAL** --

# DÉVELOPPEMENT D'UN SYSTÈME INFORMATISÉ DE MESURE POUR DETERMINER LA DUREE DE CORROSION DE METAUX DANS DES CONDITIONS D'HUMIDITE

**préparé pour:**

CONSEIL NATIONAL DE RECHERCHE DU CANADA
Institut de Génie des Matériaux
75 boul. de Mortagne
Boucherville, Québec J4B 5K5

Septembre 1986 PROJET CDT-P996

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Septembre 1986

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# RAPPORT FINAL

## *Projet 10SD-31950-4-0029*

## *Résumé*

Le projet intitulé: «Développement d'un système informatisé de mesure pour déterminer la durée de corrosion de métaux dans des conditions d'humidité » [1] a atteint ses objectifs tant sur le plan matériel que logiciel. Le système d'acquisition de données mis au point au département de génie électrique de l'Ecole Polytechnique s'est avéré tout à fait compétent. La transformation des circuits de mesure pour les adapter aux capteurs Sereda et pour les faire opérer sous une gamme de température hiver-été a été réalisée avec succès. Les logiciels d'interrogation des points de mesure, et de la gestion générale du système d'acquisition des données opèrent correctement.

## 1 - INTRODUCTION

Pour évaluer efficacement la corrosion des matériaux de construction dans l'atmosphère, il ne suffit pas d'exposer des coupons aux intempéries pendant plusieurs mois ou quelques années et de mesurer ensuite leur perte de poids, il faut aussi quantifier les conditions à l'origine de la corrosion. Pour ce faire, le "temps de mouillage ou time of wetness" (TOW) des surfaces à l'étude représente le paramètre le plus important. De plus, il importe d'effectuer les mesures in situ, sur des bâtiments réels pour tenir compte des effets des microclimats. Voici l'origine de ce contrat qui avait pour objectif d'adapter aux besoins de l'Institut de Génie des Matériaux, un appareil mis au point à l'Ecole Polytechnique. Le système de mesure des temps de mouillage est maintenant opérationnel.

## 2 - ADAPTATION DU SYSTEME DE L'ECOLE POLYTECHNIQUE

### A - MATERIEL

Basé sur un Apple II + le système de Polytechnique peut, à l'aide de quelques circuits spécialisés, interroger des circuits adressables porteurs de senseurs appropriés, et distribués au besoin le long d'une paire de fils. De nouveaux circuits de mesure ont dû être conçus pour s'adapter aux senseurs Sereda [2], pour leur présenter une impédance de charge de 10 mégohms, selon les exigences d'une norme ASTM et aussi pour pouvoir opérer à des températures variant de -30°C à +30°C.

Les nouveaux circuits opèrent correctement, ils utilisent un amplificateur opérationnel à grande stabilité (LM108) et d'un convertisseur tension-fréquence (AD537) de grade quasi-militaire. Des mesures exhaustives en four et en chambre froide ont éprouvé la performance des circuits de -40°C à +60°C. Ceux-ci ont démontré une précision et une stabilité suffisantes pour évaluer le TOW sans erreur appréciable mais depuis la publication de ces résultats [3], la stabilité des circuits a été de beaucoup améliorée. Les circuits de mesure de température se sont avérés précis à ±1°C sur la gamme de température d'intérêt.

## B - LOGICIEL

Les logiciels utilisés se divisent en deux groupes: ceux de langage d'assembleur et ceux de langage de haut niveau (BASIC).

Les programmes de bas niveau gèrent l'horloge en temps réel et manipulent l'interrogation du circuit de mesures et le retour de leurs données. Ils opèrent depuis plusieurs mois sans problème.

Les programmes en BASIC contrôlent l'interface avec l'usager, ils jouent les rôles suivants:

- interrogation continuelle d'un seul circuit de mesure, pour fins de vérification et d'étalonnage;
- organisation des tableaux pour la gestion des circuits de mesure de TOW et de température;
- calcul des TOW selon un seuil programmable;
- énregistrement et impression automatiques et continuels des TOW de chaque capteur Sereda et des températures.

Les programmes permettent aussi une opération supplémentaire, en surplus des exigences de la proposition initiale: ils permettent d'ajouter ou d'enlever un ensemble de points de mesure associés à une expérience sans déranger l'opération d'une autre expérience en cours, sans perte de données et sans obliger l'usager à effectuer des opérations longues ou ardues de remise en marche du système. Puisque l'appareil peut supporter jusqu'à 256 points de mesure, et que les expériences in situ doivent durer plusieurs mois, cette caractéristique est très intéressante.

Le travail réalisé a donné lieu à une présentation à l'ISMM en février 1986 à Beverly Hills CA. Une copie de la publication correspondante, jointe en annexe, explicite les détails des résultats obtenus [3].

## 3 - **CONCLUSION**

Les objectifs du projet tels que définis en (1) ont été pleinement réalisés. Le système d'acquisition de données avec les capteurs SEREDA, pour mesurer les TOW opère tel que promis et il ne reste qu'à le mettre à l'épreuve dans une situation réelle sur un bâtiment existant.

## 4 - **REFERENCES**

[1] Proposition: «Développement d'un système informatisé de mesures pour déterminer la durée de corrosion de métaux dans des conditions d'humidité», Projet CDT-P996, décembre 1986, Ecole Polytechnique.

[2] Epitek Electronics Inc., Commerce Park, Ogdensburg, N.Y. 13669.

[3] APRIL, G.E., PINON, C., HECHLER, J.J., DUFRESNE, R., «Atmospheric Corrosion Studies with Computer Monitoring», ISMM International Symposium on Software and Hardware Applications of Microcomputer, Los Angeles, du 5 au 7 février 1986, p. 212-215.

# ATMOSPHERIC CORROSION STUDIES WITH MICROCOMPUTER MONITORING

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Bechler J.J.

*Abstract* -- Measurements of time of wetness using Sereda sensors to evaluate, in situ, corrosive conditions for building materials are accomplished with a data acquisition system developed at Ecole Polytechnique de Montréal, Qué., Canada. It consists of a low cost Apple II+ system as a central unit, plus a single pair of wires as a communication link and as many as 256 addressable measuring circuits. The ASTM requirement for an input impedance of 10 MΩ to be presented to the Sereda sensors was met successfully, from -45°C to +60°C. Programs in machine language and in BASIC keep time, interrogate sensors and control data display, printing and storage. They also provide a friendly interface. The system can accommodate many unsynchronised corrosion tests without interruption or loss of data.

## I - INTRODUCTION

Traditionnaly, atmospheric corrosion studies are performed on ASTM racks (1). However, the results obtained with standard corrosion coupons do not generate information on how materials weather on buildings, bridges, etc., where microclimates occur. It is important to determine, in real-life situations, the time during which corrosive conditions prevail and this, over periods of many months. To the best of our knowledge, this subject remains almost unexplored.

The problem of studying existing structures is related to their complexity and to the cost of installing sensors and a communication network to its central processing unit. Costs rise quickly, especially if a pair of wires is required to link each sensor to the central unit or to one of its satellites, as is the case with most data acquisition systems. Also, the flexibility of any data acquisition network must be matched by a corresponding efficiency in the control software.

A data acquisition system developed at l'Ecole Polytechnique de Montréal (Québec, Canada) provides the required flexibility of installation and modification. It has the further advantage of being a low cost system, operating with an Apple II series computer or equivalent. The system's general organization is shown schematically in Figure 1.

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SYSTEM CONFIGURATION

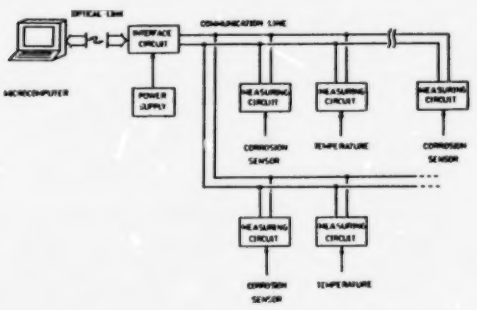


Fig. 1 General System Configuration

## II - CORROSION MEASUREMENTS

The conditions conducive to the corrosion of metals and of building materials in general, might be evaluated with a relative humidity sensor. However, a Sereda (TM) sensor manufactured by Epitek (2) would produce more significant information on surface conditions. The sensors considered in this paper consist of two tiny combs, of gold and copper inserted into one another and deposited on an epoxy base; the sensitive area covers 9mm by 10mm. Figure 2 shows the response of Cu/Au sensors to exposure for a) summer and b) winter conditions in Ottawa, Canada (3).

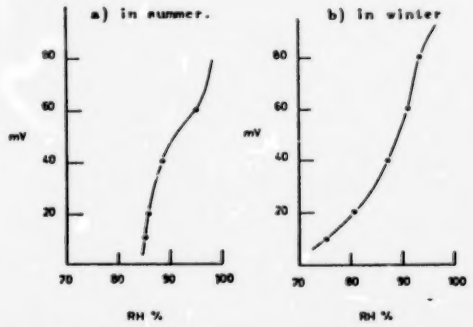


Fig. 2 Electrical response of Sereda sensors to relative humidity - a) in summer. - b) in winter

It is clear that the Sereda sensor responds to humidity in air with a marked threshold near 70 to 80 % RH. This behavior is interpreted as follows: when the ambiant air is sufficiently humid, moisture on the sensor provides an electrically conductive path between the electrodes and an electro-chemical e.m.f. is generated.

The dynamic range of this e.m.f. extends from zero to a few hundred millivolts, but following ASTM (4), 20 millivolts is interpreted as indicating the onset of corrosive conditions; thus the "time-of-wetness", (TOW), of materials under study is defined as the total time spent by the materials, when the Sereda sensors' output exceeds this 20 mV level.

The electrical source impedance of the Sereda sensor varies considerably, from tens of megohms when the sensor is dry, to a few kilohms when it is wet. However, ASTM demands that the output of the Sereda sensor be measured by a 10 megohms input impedance circuit, and this at any temperature. Finally, such surface-effect sensors must be expected to be very sensitive to air pollutants and indeed, attempts to determine a close correlation between their response and RH measurements failed completely (3).

## III - DATA ACQUISITION SYSTEM

General description

The data acquisition system was first developed using a Rockwell AIM-65 microcomputer, the onetime workhorse of many laboratories. Although the 20 character display and incorporated printer proved very well-suited to development work, it appeared insufficient for a corrosion specialist who demands a friendlier interface and a more competent display. Hence, the system was transferred to an Apple II series computer. This was done without excessive pain since both microcomputers use the same 6502 CPU.

The Apple II+ computer, through a 6522 VIA card, controls an interface circuit which drives a communication line consisting of a single pair of wires. This line can branch off at will and can support as many as 256 addressable measuring circuits, distributed as needed and with no regard to polarity. The line provides power to all the measuring circuits. Optically coupled to the Apple central computer, it is electrically floating, which enhances noise immunity. Of course, the whole system is energised by an uninterruptible power supply.

Measuring circuits

A measuring circuit covers a 4cm square printed circuit board and consists of an address decoder and an analog measuring circuit.

The address decoder analyses the addresses appearing on the line and compares them with its own address. When an incoming address corresponds to the resident address, the analog measuring circuit is activated; it responds by drawing a pulsating current from the line, at a frequency up to 10 kHz and proportional to the output of its attached sensor. This current will be detected and interpreted by the central computer. The analog measuring circuit uses an AD 537 Analog Device voltage-to-frequency converter driven by a sensor conditioning circuit.

Interfacing the measuring circuit to the Sereda sensor was no simple task because of the high input impedance (10 megohms) dictated by ASTM and also because of the broad range of outdoor temperatures in Montréal (± 30°C ) or (-20°F to 85°F). Military grade components were required and a very low bias and offset current operational amplifier such as the LM 108A had to be used . Heavy filtering with a cut-off frequency of less than 2 Hz is used in the input stage of the circuit to eliminate 60 Hz and other parasites. The input dynamic interval is set from 0 to 250 mV but other intervals can easily be obtained with a suitable choice of resistances.

The analog measuring circuit was primarily designed to operate as a high input impedance voltmeter but it can easily be modified to work as a current or as a resistance meter. Thus, it is possible to interface it to most physical sensors. Also the AD 537 by itself can be used as a temperature sensor.

Results from tests performed on the millivoltmeter from - 45° C to + 80° C will be presented in a later section of this paper.

## IV - SOFTWARE

The software of the system operates at two levels: machine language and BASIC. The two exchange values with the PEEK and POKE commands.

Under continuously running interruptions, machine-language subroutines are executed which perform the three following tasks:

1) time management: the program reads the battery-backed real-time clock, refreshes the registers to be accessed by the BASIC program and displays the hours and minutes on the screen.

2) address generation: on a signal from BASIC, it reads from a memory location the address of the next measuring circuit to be activated, and following a definite "pulse position modulation" (PPM) protocol, drives an opto-isolator on the interface circuit which controls the communication line.

3) response decoder: the program determines the frequency of the signal received from another opto-isolator on the interface circuit. This opto-isolator is excited by the current pulses drawn from the line by the enabled measuring circuit. The result is put into a memory location to be read by the BASIC program.

The high level BASIC software is very interactive: menus help the user to set the computer to operate in different modes. Easy recovery from input errors is provided.

In the initialisation mode, the user can create and modify a list of measuring points where each point is identified as a corrosion point or a temperature point.

In the automatic operation mode, the computer continuously scans the measuring points at the rate of one per second. The reading of each point is immediately displayed in a scrolling table on the screen. The program integrates the time of wetness for each of the measuring points of corrosion. It is possible to save on disk and print-out the readings periodically for further analysis.

Because the system must operate over periods of many months, the high level software is designed to offer great flexibility to the user. Indeed, each corrosion test may involve many measurement points at its own site and many tests could be performed in parallel at different sites. Also they may well begin and end on different dates. Perturbations of the system or loss of data are not acceptable, of course.

The system provides the user with the possibility of satisfying these conditions. The operator need only modify the list of measuring points according to the new network configuration, using the BASIC program in the initialisation mode. Measuring circuits with corresponding addresses are then simply added to or removed from the line at the desired locations. The system's operation remains unperturbed except that the measuring points are not interrogated while the list is being modified.

## V - EXPERIMENTAL RESULTS

### Software

The machine language program has efficiently interrogated measuring circuits unfailingly for months. Time measurement with a real-time clock with battery back-up has proved reliable. The high level language program operates efficiently: a user has yet to make it crash. The software is considered totally satisfactory, at this stage of development.

### Hardware

Measuring TOW: Data collection with Sereda sensors is just beginning and in view of the long term nature of corrosion tests, results will be reported later.

However, the stringent conditions of northern climates imposed extended testing in controlled temperature chambers, before measurements of corrosion conditions could begin. Tests covered a wider range of temperatures (from -45°C to 60°C or -50°F to 140°F) than required by the design operating interval (± 30°C).

A measuring circuit was exposed to temperatures ranging from -20°C to -45°C and back, in steps, during a 10 day period. The circuit showed no loss of performance and a total absence of hysteresis. Then tests were carried out at higher temperatures.

Figure 3 displays the performance of the millivoltmeter. "$v_{in}$" is a measured DC input, "$v_{out}$" is the result appearing on the screen of the monitor as generated by the whole measuring system.

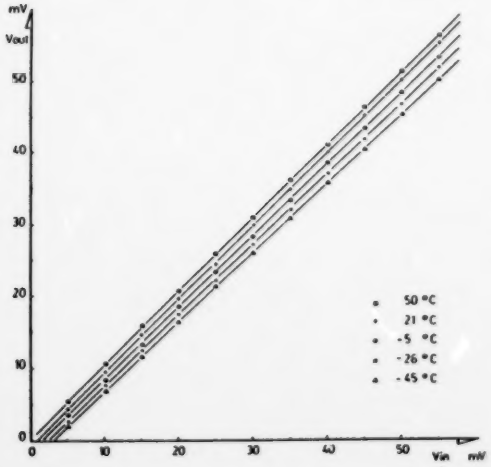


**Fig. 3 Performance of the millivoltmeter**

The graph shows measurements up to 50 mV, to cover the 20 mV critical interval with respect to the evaluation of TOW. Voltage gain appears very stable; the offset is related to the temperature sensitive output impedance of the switching regulator negative power supply in the measuring circuit, and will be corrected for the TOW measurements. Results of extensive measurements are summarized in Table 1.

| Temperatures | Input voltages | Max. errors $\frac{v_{in} - v_o}{v_{in}} \times 100\ \%$ |
|---|---|---|
| 20°C to 40°C | 20 mV to 250 mV | -1 % to +1 % |
| 10°C to 60°C | 20 mV to 250 mV | -3 % to +3 % |
| 0°C | 20 mV | - 6 % |
| -30°C | 20 mV | -14 % |
| -45°C | 20 mV | -20 % |

Table 1

Relative uncertainties in the response of the system as a function of temperature for various input voltages.

These figures might not suggest a very great precision, in our space age. A detailed analysis of uncertainties is not warranted here, but results must be evaluated in the light of this experiment. For example, at -30°C, the threshold for TOW drops from 20mV to 17 mV. From Figure 2, the rate of change of Sereda sensors varies from 2 to 12 or more mV per % RH, at 70 - 80 % RH. Such variations generally usually occur within a few minutes so that the error in the exact moment of transition has little influence on the overall TOW, measured over many months. Furthermore, at very low temperatures, where errors are larger, corrosion is relatively inactive; moreover such low temperatures occur infrequently in most regions of interest.

Above 10°C (50°F) where corrosion might be intense, the relative error is less than 2 % and decreases with increasing temperature and increasing values of input voltages.

Therefore, the evaluation of TOW is very little affected by the uncertainties in the millivoltmeter, and the data acquisition system presented is very satisfactory.

## VI - CONCLUSION

In order to evaluate the duration of corrosive conditions for building materials, the data acquisition system developed at Ecole Polytechnique de Montréal has shown to be very well suited to perform measurements of time of wetness using Sereda sensors. The single pair of wires used as a communication line supporting up to 256 addressable measuring circuits, provides for high flexibility in both the installation and the modification of the sensor network.

Machine and high level programs match the hardware flexibility and allow the user to accomodate overlapping corrosion experiments.

Addressable measuring circuits act as remote, 10 MΩ input impedance, high sensitivity voltmeters, and can operate reliably over a wide (±30°C) temperature interval. Although sufficient for the

evaluation of "time of wetness" in corrosion studies, the accuracy of the circuit might need to be improved at very low temperatures for other applications. Indeed, sensors for many other physical parameters can easily be interfaced.

Along with measuring circuits, the line can support control circuits, each with 4 opto-isolated, 8 A 110 Vrms TRIACS, independently addressable. Applications in retrofit building energy management systems, aquaculture, equipment maintenance, etc, are being considered.

## VI - REFERENCES


[1] ASTM Standard G. 60.

[2] Epitek Electronics Inc., Commerce Park, Ogdensburg, N.Y. 13669

[3] P.J. Sereda, S.C. Scroll and H.F. Slade, "Atmospheric Corrosion of Metals", ASTM STP 767, 1982, pp. 267-283

[4] ASTM Standard G. 84.



Keywords: corrosion, atmospheric, data acquisition microcomputer, bus configuration.